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(54) GAS NETWORK AND METHOD FOR DETECTING LEAKS IN A GAS NETWORK UNDER PRESSURE OR UNDER VACUUM

GASNETZ UND VERFAHREN ZUR DETEKTION VON LECKS IN EINEM GASNETZ UNTER DRUCK ODER UNTER VAKUUM

RÉSEAU DE GAZ ET PROCÉDÉ DE DÉTECTION DE FUITES DANS UN RÉSEAU DE GAZ SOUS PRESSION OU SOUS VIDE

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• **ABDULLA MOHAMMAD BURHAN ET AL:**
"Pipeline leak detection using artificial neural network: Experimental study", 2013 5TH INTERNATIONAL CONFERENCE ON MODELLING, IDENTIFICATION AND CONTROL (ICMIC), CAIRO UNIVERSITY, EGYPT, 31 August 2013 (2013-08-31), pages 328 - 332, XP032513843

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Description

[0001] Gas network and method for detecting leaks in a gas network under pressure or under vacuum.

[0002] The current invention relates to a method for detecting leaks in a gas network under pressure or under vacuum according to appended claim 1 and to a gas network under pressure or under vacuum according to appended claim 10.

[0003] More specifically, the invention is intended to be able to detect and quantify leaks that occur in a gas network.

[0004] "Gas" herein means for example air, but not necessarily.

[0005] Methods for monitoring or controlling a gas network under pressure are already known, whereby these methods are set up for long and straight pipelines, where the incoming flow is not necessarily equal to the outgoing flow due to the compressibility of the gas in question.

[0006] These methods are based on a number of assumptions such as very long pipelines, straight pipelines, which are not suitable for complex gas networks under pressure where one or more compressor plants supply gas under pressure to a complex network of consumers.

[0007] Also, methods are already in place, as described in US 7.031.850 B2 and US 6.711.507 B2, to detect leaks in pneumatic components or tools of the final consumers themselves. A final consumer may be an individual final consumer or include a so-called consumer area or a group of individual final consumers.

[0008] Methods for estimating the total leakage rate on the source side are also known from e.g. DE 20.2008.013.127 U1 and DE 20.2010.015.450 U1. In ABDULLA MOHAMMAD BURHAN ET AL: "Pipeline leak detection using artificial neural network: Experimental study", 2013 5TH INTERNATIONAL CONFERENCE ON MODELLING, IDENTIFICATION AND CONTROL (ICMIC), CAIRO UNIVERSITY, EGYPT, 31 August 2013 (2013-08-31), pages 328-332, a detection network using a neural network is disclosed. In US 6 389 881 B1, an acoustic pipeline leak detection and location method is disclosed. In US 2005/234660 A1 a method and apparatus for diagnosing leakage in a fluid power system is disclosed. In GB 2 554 950 A, a method for estimating characteristics of a new leak is disclosed. In WO 2016/161389 A1, an autonomous identification of an anomalous aqueous system is disclosed.

[0009] The disadvantage of such known methods is that they do not allow for the detection of leaks in a complex network of pipelines between the source and the consumers or consumer areas. In addition, the distribution network of a gas or vacuum network is a source of leaks that should not be underestimated.

[0010] The aim of the current invention is to provide a solution to this problem.

[0011] The current invention relates to a method for detecting and quantifying leaks in a pressurized or vacuum gas network, according to appended claim 1.

[0012] 'A predetermined order' in which the adjustable relief valves are controlled means the order in which the adjustable relief valves are opened and closed, in case there is more than one.

[0013] 'Scenarios' refers to the different on and off states of the different relief valves, for example: [0 0 0 0], [1 0 0 0], [0 1 1 0], ... in the case of four relief valves. It is possible that there are more states than just on (1) and off (0), where an intermediate state (e.g. 1/2) is equally important for leak detection and quantification.

[0014] The 'derivative of the difference' means any mathematical quantity that can be extracted from the difference, for example a sum, cumulative sum, arithmetic mean, smallest squares sum ...

[0015] The 'consumer area' refers to a group of individual (final) consumers. A gas network may contain several consumer groups or consumer areas.

[0016] An advantage is that such a method will make it possible to learn, detect and also quantify leaks in the gas network itself.

[0017] In other words, the leaks detected and quantified by the method are not limited to leaks in the sources or consumers of compressed gas, i.e. in the compressor plants and pneumatic tools or components, but may also concern leaks in the distribution pipelines of the gas network itself.

[0018] It should be noted that in the case of a gas network under pressure, leaks will occur to the outside and gas will escape to the surrounding area. In a vacuum gas network, leaks will occur 'inwards', i.e. ambient air will enter the gas network.

[0019] During the training phase, using the measurements of the various sensors, a relationship is established between this group of sensors.

[0020] Different measurements are made at different settings of the relief valves. In other words, different leaks are generated in the gas network in a specific designed sequence under different test scenarios and then the measurements of the sensors are read out.

[0021] On the basis of all the data, a mathematical model is established between the first group of sensors, or the input of the mathematical model, and the second group of sensors, or the output of the mathematical model. The input or mathematical manipulations are also called 'features' of the mathematical model and the output is also called 'targets'.

[0022] In this way, a mathematical model will be created that shows the relationship between the different parameters measured by the sensors.

[0023] This model will then be used to immediately detect irregularities in future measurements of the sensors by comparing the results of the model and the measurements of the sensors.

[0024] In this way, leaks will be detected, located and quantified very quickly and accurately and, in case of detection of a leak, action can be taken and the leak can be repaired.

[0025] An additional advantage of a method in accor-

dance with the invention is that the exact topology of the gas network does not have to be known. Knowing the location of the relief valves is basically sufficient to be able to detect, quantify and locate the leaks.

[0026] Another advantage is that the method according to the invention takes into account the entire gas network and can therefore detect, quantify and locate leaks in the entire gas network. This means that the network should not be divided into 'sub-networks' to which the method is applied in order to be able to apply the method.

[0027] Another advantage is that the method makes it possible to use measurements or datasets from the sensors in the training phase to create the mathematical model, where leaks are simulated, instead of having to use data from the sensors, where 'real' leaks occurred in the gas network. The generation of the necessary data from the sensors is therefore necessary in order to be able to draw up the mathematical model, not dependent on any leaks that may have occurred in the past.

[0028] Preferably, the operational phase should be temporarily interrupted or stopped at certain times, after which the training phase should be resumed in order to redefine the mathematical model or the relationship between the measurements of different sensors, before the operational phase is resumed.

[0029] It should be noted that the process, i.e. the gas network with sources, pipelines and consumers, is not shut down, but only the method. In other words, if the operational phase is temporarily interrupted or stopped, the sources will still supply gas or vacuum to the consumers.

[0030] Interrupting the operational phase and resuming the training phase has the advantage that the mathematical model or relationship is updated.

[0031] This will make it possible to take into account, for example, detected leaks that are being repaired or adjustments or expansions to the gas network that are being made over time.

[0032] The invention also concerns a gas network under pressure or under vacuum, according to appended claim 10.

[0033] To better demonstrate the characteristics of the invention, a number of preferred variants of a method and gas network in accordance with the invention have been described below, by way of example without any restrictive character, with reference to the accompanying drawings, in which:

figure 1 schematically shows a gas network according to the invention;

figure 2 shows a schematic flowchart of the method in accordance with the invention.

[0034] The gas network 1 in figure 1 comprises mainly a source side 2, a consumer side 3 and a network 4 of pipelines 5 between the two. The gas network 1 in this case is a gas network 1 under pressure. The gas can be

air, oxygen or nitrogen or any other non-toxic and/or hazardous gas or mixture of gases.

[0035] The source side 2 comprises a number of compressors 6, in this case three, which generate compressed air. The consumer side 3 comprises a number of consumers 7 of compressed air and in this case also three.

[0036] It is also possible that the compressors 6 contain compressed air dryers.

[0037] It is not excluded that there may also be compressors 6 downstream of the gas network 1. This is referred to as "boost compressors".

[0038] The compressed air is routed through the network 4 of pipelines 5 from the compressors 6 to the consumers 7. This network 4 is in most cases a very complex network of pipelines 5.

[0039] Figure 1 shows this network 4 in a very schematic and simplified way. In most real situations, the network 4 of pipelines 5 comprises a large number of pipelines 5 and couplings that connect the consumers 7 in series and in parallel with the compressors 6. It is not excluded that part of the network 4 adopts or comprises a ring structure.

[0040] This is because the gas network 1 is often extended over time with additional consumers 7 or compressors 6, whereby new pipelines 5 between the existing pipelines 5 have to be laid, which leads to a tangle of pipelines 5.

[0041] The gas network 1 may also be provided with a pressure vessel 8, with all compressors 6 in front of this pressure vessel 8.

[0042] It is not excluded that there may be one or more pressure vessels 8 downstream of the gas network 1.

[0043] In addition, components 18, such as filters, separators, atomizers and/or regulators, can also be provided in the gas network 1. These components 18 can be found in various combinations and can be found both near the buffer tank 8 and close to the individual consumers 7.

[0044] Network 4 also includes a number of sensors 9a, 9b, 9c, which are located at different locations in network 4.

[0045] In this case, two flow sensors 9a have been installed, one of which is just after the aforementioned pressure vessel 8, which will measure the total flow q provided by all compressors 6.

[0046] It is not excluded that the flow rates of the compressors 6 are calculated or measured by themselves.

[0047] In addition, the figure shows four pressure sensors 9b, which measure the pressure at different locations in the network 4.

[0048] In this case, the pressure 9b in the pressure vessel is preferably also measured to correct the "mass in - mass out" principle for large, concentrated volumes.

[0049] It is clear that more or less than four pressure sensors 9b can also be provided. In addition, the number of flow sensors 9a is not limiting for the invention.

[0050] In addition to flow sensors 9a or pressure sensors 9b, additionally, or alternatively, sensors 9a, 9b may be used to determine one or more of the following physical parameters of the gas: differential pressure, temperature, humidity, gas velocity and the like.

[0051] In accordance with the invention, the gas network 1 is also provided with a number of relief valves 10 which are installed in the pipelines 1 at various locations. The relief valves 10 are adjustable or controllable, which means that the amount of gas they vent can be adjusted or regulated.

[0052] In addition to the aforementioned sensors 9a and 9b, which can measure the physical parameters of the gas, there are also a number of sensors 9c, or 'state sensors 9c', which are located at the relief valves 10. Preferably the sensors 9c are part of the relief valve 10.

[0053] Although not explicitly indicated in figure 1, it cannot be excluded that in the gas network 1 there are additional state sensors 9c in the vicinity of the compressors 6 and the consumers 7 that determine the on/off state of these components. Preferably, these state sensors are part of the consumers 7 themselves.

[0054] The additional state sensors 9c (e.g. on/off of the compressors 6) then aim to significantly reduce the cross-sensitivity of the model during the training phase 16 and the operational phase 17, as will be explained below.

[0055] It is also possible to use sensors 9a, 9b which measure the pressure or flow of the gas at the relief valves 10. It is also possible to use sensors which measure the temperature of the gas at the relief valves 10.

[0056] The relief valves 10 can be formed by drainage valves, which are often provided as standard in a gas network 1. Such drainage valves can be controlled as a relief valve 10.

[0057] At least some of the flow sensors, pressure sensors, alternative sensors and/or state sensors 9a, 9b, 9c should preferably be located in the vicinity of the relief valves 10. In this case, each flow sensor 9a and each status sensor 9c are placed in the vicinity of a relief valve 10.

[0058] In this case, the flow sensor 9a will be used to measure the flow rate of the respective relief valve 10, which will allow quantification of the leakage flow, and the state, i.e. open or closed, of the relief valve 10 can be determined using the state sensor 9c.

[0059] Preferably, a sensor 9a, 9b, 9c and/or vice versa should be provided in the vicinity of each relief valve 10 in the gas network 1, i.e. a relief valve 10 should be provided near each sensor 9a, 9b.

[0060] It is also possible that at least part of the sensors 9a, 9b, 9c are integrated in one module together with a relief valve 10.

[0061] This will also simplify and speed up the installation or integration of the sensors 9a, 9b, 9c and the relief valves 10. In addition, it can be ensured that a correct and suitable sensor 9a, 9b, 9c for the relief valves 10 is placed together in one module.

[0062] The aforementioned differential pressure sensors 9d are preferably placed over filter, separator, atomizer and/or regulator components 18. In the current example, four differential pressure sensors 9d have been incorporated into the gas network 1.

[0063] The aforementioned humidity and temperature sensors should preferably be mounted on the inlet/outlet of compressor plants 6 and the consumers 7. In the example shown, these additional sensors are not all included in the gas network 1, but it goes without saying that this is also possible. Especially in more extensive and complex gas networks 1 such sensors 9a, 9b can be used, as well as in networks where only the volumetric flow rate is measured instead of the mass flow rate.

[0064] In accordance with the invention, the gas network 1 is further provided with a data acquisition control unit 11 to collect data from the aforementioned sensors 9a, 9b, 9c, 9d and also to control the relief valves 10.

[0065] In other words, sensors 9a, 9b, 9c, 9d determine or measure the physical parameters of the gas and the relief valves 10 and send this data to the data acquisition control unit 11, and the data acquisition control unit 11 will control or check how much the relief valves 10 are opened to vent the gas.

[0066] In accordance with the invention, the gas network 1 is further provided with a computing unit 12 for processing the data from sensors 9a, 9b, 9c, 9d, wherein the computing unit 12 will be able to carry out the method for detecting and quantifying leaks 13 in the gas network 1 in accordance with the invention, as explained below.

[0067] The aforementioned computing unit 12 can be a physical module which is a physical part of the gas network 1. It cannot be excluded that the computing unit 12 is not a physical module, but a so-called cloud-based computing unit 12, which may or may not be connected wirelessly to the gas network 1. This means that the computing unit 12 or the software of computing unit 12 is located in the 'cloud'.

[0068] In this case, the gas network 1 is further provided with monitor 14 to display or signal leaks 13 that were detected using the method.

[0069] The operation of gas network 1 and the method in accordance with the invention is very simple and as follows.

[0070] Figure 2 schematically illustrates the method for detecting leaks 13 in the gas network 1 of figure 1.

[0071] In the first phase 15, start-up phase 15, sensors 9a, 9b, 9c, 9d are calibrated before use if necessary. It goes without saying that if there are other sensors, they can also be calibrated before use.

[0072] This happens once when the sensors 9a, 9b, 9c, 9d are placed in the gas network 1. Of course, it is possible that sensors 9a, 9b, 9c, 9d may be recalibrated over time.

[0073] Preferably, at least the group of sensors 9a should be calibrated during operation or by means of an in-situ self-calibration. This means that these sensors 9a in the gas network 1, i.e. after they have been installed,

are calibrated. "In operation" or "in situ" means calibration without removing the sensor 9a from the gas network 1.

[0074] It is of course possible that all sensors 9a, 9b, 9c, 9d and thus also the first group of sensors 9a, 9b, 9c or 9d will be calibrated in operation or in situ by means of a self-calibration.

[0075] In this way one can be sure that the placement and/or possible contamination of the sensors 9a, 9b, 9c, 9d will not affect their measurements, because only after the placement of the sensors 9a, 9b, 9c, 9d will you perform the calibration or repeat the calibration for a certain period of time.

[0076] Then the second phase 16 or the training phase 16 starts.

[0077] In this phase, a mathematical model is made between the measurements of a first group of sensors 9a, 9b, 9c, 9d or the 'features' and a second group of sensors 9a, 9b, 9c, 9d or the 'targets'.

[0078] Preferably, the first group of sensors 9a, 9b, 9c, 9d includes several pressure sensors 9b at different locations in the gas network, a number of flow sensors 9a and possibly one or more state sensors 9c, and the second group of sensors 9a, 9b, 9c, 9d includes several flow sensors 9a at different locations in the gas network.

[0079] In this case, part of the flow sensors 9a, the pressure sensors 9b and the status sensors 9c form the first group of sensors, and the remaining flow sensors 9a form the second group of sensors.

[0080] For the sake of completeness, it is stated here that the invention is not limited to this. For the first and second group of sensors, any selection can be made from the sensors (9a, 9b, 9c, 9d), with the only restriction that a sensor in the first group should not be in the second group and vice versa.

[0081] The aforementioned mathematical model is based on various measurements of sensors 9a, 9b, 9c, 9d where the adjustable relief valves 10 are controlled to generate leaks.

[0082] In other words, the data acquisition control unit 11 collects data or measurements from sensors 9a, 9b, 9c, 9d where the data acquisition control unit 11 will control the relief valves 10 in order to be able to open them so that leaks are created in the gas network 1, so that data can be collected from sensors 9a, 9b, 9c, 9d in case of a leak or leaks 13 in the gas network 1.

[0083] In this way, a whole set of data or measurements can be collected, together with the information from the relief valves 10, i.e. the location and size of the introduced leaks. The computing unit 12 will make a mathematical model on the basis of all this information. This mathematical model is preferably a black-box model or a data-driven model. The model typically contains a number of parameters or coefficients, also called 'weights', which are estimated.

[0084] This black-box model, for example, takes the form of a matrix or a non-linear mathematical vector function or the like.

[0085] The mathematical model is based on a number

of assumptions. In this case, it is assumed that the resistance of the pipelines 5 of the gas network 1 does not change and that the topology of the gas network 1 is fixed.

5 **[0086]** The training phase 16 should preferably be carried out during the operation of the gas network 1 or when the gas network 1 is operational.

[0087] The mathematical model is used in an operational phase 17 to detect and quantify leaks 13 in the gas network 1. Although not common, it cannot be excluded that during the operational phase the relief valves 10 are controlled in a predetermined order and scenario to locate leaks 13. It should be noted that control in accordance with scenario [0 0 0 ...] is also possible.

10 **[0088]** Also during this phase, the data acquisition control unit 11 will collect different data from the sensors 9a, 9b, 9c, 9d and the computing unit 12 will perform the necessary calculations using the mathematical model that was set up in the previous phase 16.

15 **[0089]** The operational phase 17 starts with the reading of the first group of sensors 9a, 9b, 9c, 9d.

[0090] With these read measurements, the value of the second group of sensors 9a is determined or calculated by the computing unit 12 using the mathematical model, also called 'predicted target'.

20 **[0091]** The determined or calculated value of the second group of sensors 9a is compared with the read values of the second group of sensors 9a and the difference between them is determined.

25 **[0092]** On the basis of the aforementioned difference, the computing unit 12 determines whether there is a leak 13 and, if necessary, locates the leak in the gas network 1.

[0093] For this purpose, it will be examined whether the difference exceeds a certain threshold, which will then indicate a leak 13 in the gas network 1.

30 **[0094]** This threshold value can be set in advance or selected empirically.

[0095] When a leak 13 is detected, an alarm will be generated with possibly the corresponding leakage rate and/or the leakage cost. In this case, this is done using monitor 14, which displays the alarm.

35 **[0096]** The user of the gas network 1 will notice this alarm and be able to take the appropriate steps.

[0097] The steps of the operational phase 17 are preferably repeated sequentially, cyclically, at a certain time interval.

[0098] As a result, during the entire operational period of the gas network 1, leaks 13 can be detected, and not just once during or shortly after the start up of the gas network 1.

40 **[0099]** The aforementioned time interval can be selected and set depending on the gas network 1. It cannot be excluded that the time interval may vary over time.

45 **[0100]** In a preferred variant of the invention, at certain moments, the operational phase 17 will be temporarily interrupted or stopped, after which the training phase 16 will be resumed in order to re-establish the mathematical relationship between the measurements of different sen-

sors 9a, 9b, 9c, 9d, before the operational phase 17 is resumed.

[0101] 'At certain moments' should herein be interpreted as moments that are preset, for example once a week, per month or per year, or as moments that can be chosen by the user.

[0102] This will update the mathematical model to take into account the possible time-varying behavior of the system. These time-varying behaviors are behaviors that were not captured by the mathematical model during the training phase 16 when the mathematical model was trained under different scenarios.

[0103] This could include, for example, changes in the topology of gas network 1 or the addition of new components to gas network 1.

[0104] Preferably, the sensors 9a, 9b, 9c, 9d are calibrated by means of an in-situ self-calibration. This means that sensors 9a, 9b, 9c, 9d in the gas network 1, i.e. after they have been installed, are calibrated.

[0105] In this way, you can be sure that the placement of the sensors 9a, 9b, 9c, 9d will not affect their measurements, because the calibration will only be done after the placement of the sensors 9a, 9b, 9c, 9d.

[0106] Although in the example of figure 1 it concerns a gas network 1 under pressure, it can also be a gas network 1 under vacuum.

[0107] Source side 2 then comprises a number of sources of vacuum, i.e. vacuum pumps or similar.

[0108] In this case, the consumers 7 have been replaced by applications that require vacuum.

[0109] Furthermore, the method is the same, taking into account of course that leaks now introduce ambient air into the gas network 1. Preferably, smaller thresholds will be set to generate an alarm.

[0110] Also, in this case the relief valves 10 will introduce ambient air into the gas network 1, rather than blowing off real air. The relief valves 10 are therefore more likely to be suction valves 10. However, the principle remains the same.

[0111] This invention is by no means limited to the embodiments by way of example and shown in the figures, but such a method and gas network as claimed in the invention can be carried out in different variants without going beyond the scope of the invention, as defined by the appended claims.

Claims

1. Method for detecting and quantifying leaks (13) in a gas network (1) under pressure or vacuum, the gas network (1) comprising:

- one or more sources (6) of compressed gas or vacuum;
- one or more consumers (7) or consumer areas of compressed gas or vacuum applications;
- pipelines or a network of pipelines (5) to trans-

port the gas or vacuum from the sources (6) to the consumers (7), consumer areas or applications;

- a plurality of sensors (9a, 9b) which determine one or a plurality of physical parameters of the gas at different times and locations in the gas network (1);

characterized in that the gas network (1) is further provided with a number of controllable or adjustable relief valves (10) and that the method comprises the following steps:

- a training phase (16) in which a mathematical model is established between the measurements of a first group of sensors (9a, 9b) and a second group of sensors (9a, 9b) comprising a plurality of pressure sensors (9b), possibly a number of flow sensors (9a) and possibly number of state sensors (9c) at different locations in the gas network (1), based on different measurements of these sensors (9a, 9b), the second group of sensors comprising a plurality of state sensors (9c) at different locations in the gas network (1), wherein a sensor from the first group is not in the second group and vice versa, in which the adjustable relief valves (10) are controlled in a predetermined order and according to well-designed scenarios to generate leaks (13);

- an operational phase (17), in which the mathematical model established between the measurements of the first group of sensors (9a, 9b) and the second group of sensors (9a, 9b) is used to detect, locate and quantify leaks (13) in the gas network (1); wherein the operational phase (17) comprises the following steps:

- controlling the relief valves in a predetermined order and according to well-designed scenarios;
- reading out the first group of sensors (9a, 9b);
- based on these readout measurements, calculating or determining the value of the second group of sensors (9a, 9b) with the help of the mathematical model;
- comparing the calculated or determined values of the second group of sensors (9a, 9b) with the read values of the second group of sensors (9a, 9b) and determining the difference between them;
- determining whether there is a leak (13) in the gas network (1) on the basis of the aforementioned difference and any of its derivatives comprising a mathematical quantity extractable from the difference;
- generating an alarm if a leak (13) is detected and/or; generating a leakage rate and/or generating the corresponding leakage cost as well as any location if a leak (13) is detected.

2. Method according to claim 1, **characterized in that** at least a part of the flow sensors (9a) are placed in the vicinity of the relief valves (10) so that the flow rate of the relief valves (10) can be measured.
3. Method according to any preceding claim, **characterized in that** the method for the training phase (16) comprises a start-up phase (15) in which the aforementioned sensors (9a, 9b) are calibrated before use.
4. Method according to any of the preceding claims, **characterized in that** the operational phase (17) is temporarily interrupted or stopped at certain moments, after which the training phase (16) is resumed in order to redefine the mathematical model between the measurements of different sensors (9a, 9b) before the operational phase (17) is restarted.
5. Method according to any of the preceding claims, **characterized in that** the operational phase (17) steps are sequentially repeated at a given time interval.
6. Method according to any of the preceding claims, **characterized in that** in the vicinity of each relief valve (10) in the gas network (1), a sensor (9a, 9b) is provided and/or vice versa.
7. Method according to any of the preceding claims, **characterized in that** the mathematical model is a black-box model.
8. Method according to any of the preceding claims, **characterized in that** the aforementioned mathematical model takes the form of a matrix and/or a nonlinear vector function with parameters or constants, where the changes of the output or 'targets' of the mathematical model are tracked during the operational phase (17).
9. Method according to any of the preceding claims, **characterized in that** the gas network (1) is further provided with one or a plurality of sensors (9c) which can register the state of one or a plurality of relief valves (10) and/or that the gas network (1) is further provided with one or a plurality of differential pressure sensors (9d).
10. Gas network under pressure or under vacuum, the gas network (1) is at least provided with:
- one or more sources (6) of compressed gas or vacuum;
 - one or more consumers (7) or consumer areas of compressed gas or vacuum applications;
 - pipelines or a network of pipelines (5) to transport the gas or vacuum from the sources (6) to the consumers (7) or consumer areas ;
- a plurality of sensors (9a, 9b) providing one or more physical parameters of the compressed gas at different times and locations within the gas network (1);
- characterized in that** the gas network (1) is further provided with:
- a number of controllable or adjustable relief valves (10);
 - one or a plurality of sensors (9c) which can register the state or status of one or a plurality of relief valves (10);
 - a data acquisition control unit (11) for the collection of data from the sensors (9a, 9b, 9c) and for controlling or adjusting the aforementioned relief valves;
 - a computing unit (12) for carrying out the method according to any of the preceding claims.
11. Gas network according to claim 10, **characterized in that** in the vicinity of each relief valve (10) in the gas network (1) a sensor (9a, 9b, 9c) is provided and/or vice versa.
12. Gas network according to any of the preceding claims 10 to 11, **characterized in that** the gas network (1) is further provided with a monitor (14) to display or signal leaks, leakage rates, leakage costs and possible location (13).
13. Gas network according to any of the preceding claims 10 to 12, **characterized in that** the gas network (1) is further provided with one or a plurality of sensors (9c) which can register the state or status of one or a plurality of relief valves (10) and/or that the gas network (1) is further provided with one or a plurality of differential pressure sensors (9d).
14. Gas network according to any of the preceding claims 10 to 13, **characterized in that** the computing unit (12) is a cloud-based computing unit (12), which is connected to the gas network (1), either or not wireless.

Patentansprüche

1. Verfahren zum Erkennen und Quantifizieren von Lecks (13) in einem Gasnetz (1) unter Druck oder Vakuum, wobei das Gasnetz (1) umfasst:
- eine oder mehrere Quellen (6) von Druckgas oder Vakuum;
 - einen oder mehrere Verbraucher (7) oder Verbraucherbereiche von Druckgas- oder Vakuumanwendungen;

- Rohrleitungen oder ein Rohrleitungsnetz (5) zum Transportieren des Gases oder Vakuums von den Quellen (6) zu den Verbrauchern (7), Verbraucherbereichen oder Anwendungen;
 - eine Vielzahl von Sensoren (9a, 9b), die einen oder eine Vielzahl von physikalischen Parametern des Gases zu unterschiedlichen Zeiten und an unterschiedlichen Orten im Gasnetz (1) bestimmen;
dadurch gekennzeichnet, dass das Gasnetz (1) weiter mit einer Anzahl von steuerbaren oder einstellbaren Entlastungsventilen (10) versehen ist und dass das Verfahren die folgenden Schritte umfasst:

- eine Trainingsphase (16), in der ein mathematisches Modell zwischen den Messungen einer ersten Gruppe von Sensoren (9a, 9b) und einer zweiten Gruppe von Sensoren (9a, 9b), umfassend eine Vielzahl von Drucksensoren (9b), möglicherweise eine Anzahl von Durchflusssensoren (9a) und möglicherweise eine Anzahl von Zustandsensoren (9c) an unterschiedlichen Orten im Gasnetz (1), basierend auf unterschiedlichen Messungen dieser Sensoren (9a, 9b) erstellt wird, wobei die zweite Gruppe von Sensoren eine Vielzahl von Zustandsensoren (9c) an unterschiedlichen Orten im Gasnetz (1) umfasst, wobei ein Sensor aus der ersten Gruppe nicht in der zweiten Gruppe vorliegt und umgekehrt, in der die einstellbaren Entlastungsventile (10) in einer vorbestimmten Reihenfolge und gemäß gut entworfenen Szenarien zum Erzeugen von Lecks (13) gesteuert werden;
 - eine Betriebsphase (17), in der das zwischen den Messungen der ersten Gruppe von Sensoren (9a, 9b) und der zweiten Gruppe von Sensoren (9a, 9b) erstellte mathematische Modell verwendet wird, um Lecks (13) im Gasnetz (1) zu erkennen, zu lokalisieren und zu quantifizieren;

wobei die Betriebsphase (17) die folgenden Schritte umfasst:

- Steuern der Entlastungsventile in einer vorbestimmten Reihenfolge und gemäß gut entworfenen Szenarien;
 - Auslesen der ersten Gruppe von Sensoren (9a, 9b);
 - basierend auf diesen ausgelesenen Messungen, Berechnen oder Bestimmen des Werts der zweiten Gruppe von Sensoren (9a, 9b) mit Hilfe des mathematischen Modells;
 - Vergleichen der berechneten oder be-

stimmten Werte der zweiten Gruppe von Sensoren (9a, 9b) mit den ausgelesenen Werten der zweiten Gruppe von Sensoren (9a, 9b) und Bestimmen der Differenz zwischen ihnen;

- Bestimmen, ob ein Leck (13) im Gasnetz (1) vorliegt, auf der Basis der vorgenannten Differenz und irgendeiner ihrer Ableitungen, umfassend eine mathematische Größe, die aus der Differenz extrahierbar ist;
 - Erzeugen eines Alarms, wenn ein Leck (13) erkannt wird und/oder Generieren einer Leck-Rate und/oder Generieren der entsprechenden Leck-Kosten sowie eines beliebigen Orts, wenn ein Leck (13) erkannt wird.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** zumindest ein Teil der Durchflusssensoren (9a) in der Nähe der Entlastungsventile (10) platziert werden, so dass die Durchflussrate der Entlastungsventile (10) gemessen werden kann.

3. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** das Verfahren für die Trainingsphase (16) eine Anlaufphase (15) umfasst, in der die vorgenannten Sensoren (9a, 9b) vor Gebrauch kalibriert werden.

4. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** die Betriebsphase (17) vorübergehend unterbrochen oder zu bestimmten Zeitpunkten gestoppt wird, wonach die Trainingsphase (16) fortgesetzt wird, um das mathematische Modell zwischen den Messungen verschiedener Sensoren (9a, 9b) neu zu definieren, bevor die Betriebsphase (17) erneut gestartet wird.

5. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** die Schritte der Betriebsphase (17) in einem bestimmten Zeitintervall sequentiell wiederholt werden.

6. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** in der Nähe jedes Entlastungsventils (10) im Gasnetz (1) ein Sensor (9a, 9b) vorgesehen ist und/oder umgekehrt.

7. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** das mathematische Modell ein Black-Box-Modell ist.

8. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** das vorgenannte mathematische Modell die Form einer Matrix und/oder einer nichtlinearen Vektorfunktion mit Parametern oder Konstanten annimmt, wobei die Änderungen der Ausgabe oder "Ziele" des mathematischen

Modells während der Betriebsphase (17) verfolgt werden.

9. Verfahren nach einem der vorstehenden Ansprüche, **dadurch gekennzeichnet, dass** das Gasnetz (1) weiter mit einem oder einer Vielzahl Sensoren (9c) versehen ist, die den Zustand eines oder einer Vielzahl von Entlastungsventilen (10) registrieren können und/oder dass das Gasnetz (1) weiter mit einem oder einer Vielzahl von Differenzdrucksensoren (9d) versehen ist.

10. Gasnetz unter Druck oder Vakuum, wobei das Gasnetz (1) zumindest ausgestattet ist mit:

- einer oder mehreren Quellen (6) von Druckgas oder Vakuum;
- einem oder mehreren Verbrauchern (7) oder Verbraucherbereichen von Druckgas- oder Vakuumanwendungen;
- Rohrleitungen oder einem Rohrleitungsnetz (5) zum Transportieren des Gases oder Vakuums von den Quellen (6) zu den Verbrauchern (7) oder Verbraucherbereichen;
- einer Vielzahl von Sensoren (9a, 9b), die einen oder mehrere physikalische Parameter des Druckgases zu unterschiedlichen Zeiten und an unterschiedlichen Orten innerhalb des Gasnetzes (1) liefern;

dadurch gekennzeichnet, dass das Gasnetz (1) weiter versehen ist mit:

- einer Anzahl von steuerbaren oder einstellbaren Entlastungsventilen (10);
- einem oder einer Vielzahl von Sensoren (9c), die den Zustand oder Status eines oder einer Vielzahl von Entlastungsventilen (10) registrieren können;
- einer Datenerfassungssteuereinheit (11) zur Sammlung von Daten von den Sensoren (9a, 9b, 9c) und zum Steuern oder Einstellen der vorgenannten Entlastungsventile;
- einer Recheneinheit (12) zur Durchführung des Verfahrens nach einem der vorstehenden Ansprüche.

11. Gasnetz nach Anspruch 10, **dadurch gekennzeichnet, dass** in der Nähe jedes Entlastungsventils (10) im Gasnetz (1) ein Sensor (9a, 9b, 9c) vorgesehen ist und/oder umgekehrt.

12. Gasnetz nach einem der vorstehenden Ansprüche 10 bis 11, **dadurch gekennzeichnet, dass** das Gasnetz (1) weiter mit einem Monitor (14) versehen ist, um Lecks, Leck-Raten, Leck-Kosten und einen möglichen Orte (13) anzuzeigen oder zu signalisieren.

13. Gasnetz nach einem der vorstehenden Ansprüche 10 bis 12, **dadurch gekennzeichnet, dass** das Gasnetz (1) weiter mit einem oder einer Vielzahl von Sensoren (9c) versehen ist, die den Zustand oder Status von einem oder einer Vielzahl von Entlastungsventilen (10) registrieren können und/oder dass das Gasnetz (1) weiter mit einem oder einer Vielzahl von Differenzdrucksensoren (9d) versehen ist.

14. Gasnetz nach einem der vorstehenden Ansprüche 10 bis 13, **dadurch gekennzeichnet, dass** die Recheneinheit (12) eine Cloud-basierte Recheneinheit (12) ist, die mit dem Gasnetz (1) verbunden ist, entweder kabellos oder nicht.

Revendications

1. Procédé destiné à la détection et à la quantification de fuites (13) dans un réseau de distribution de gaz (1) mis sous pression ou sous vide, le réseau de distribution de gaz (1) comprenant :

- une source (6) de gaz comprimé ou de vide ou plusieurs de ces dernières ;
- un consommateur (7) ou une zone de consommateurs d'applications de gaz comprimé ou de vide ou plusieurs de ces derniers/dernières ;
- des pipelines ou un réseau de pipelines (5) pour le transport du gaz comprimé ou du vide à partir des sources (6) en direction des consommateurs (7), des zones de consommateurs ou des applications ;
- un certain nombre de capteurs (9a, 9b) qui déterminent un paramètre physique du gaz ou plusieurs de ces derniers à différents moments et à différents endroits au sein du réseau de distribution de gaz (1) ;

caractérisé en ce que le réseau de distribution de gaz (1) est en outre équipé d'un certain nombre de soupapes de surpression (10) qui peuvent être contrôlées ou qui peuvent être réglées ; et **en ce que** le procédé comprend les étapes suivantes, à savoir :

- une phase d'entraînement (16) au cours de laquelle on établit un modèle mathématique entre les mesures d'un premier groupe de capteurs (9a, 9b) et d'un deuxième groupe de capteurs (9a, 9b) qui comprend un certain nombre de capteurs de la pression (9b), de manière facultative un certain nombre de capteurs de l'écoulement (9a) et de manière facultative un certain nombre de capteurs d'états (9c) à différents endroits dans le réseau de distribution de gaz (1), sur la base de différentes

mesures de ces capteurs (9a, 9b), le deuxième groupe de capteurs comprenant un certain nombre de capteurs d'états (9c) à différents endroits dans le réseau de distribution de gaz (1) ; dans lequel un capteur faisant partie du premier groupe ne se retrouve pas dans le deuxième groupe, et vice versa ; dans lequel les soupapes de surpression (10) qui peuvent être réglées font l'objet d'un contrôle dans un ordre prédéterminé et en fonction de scénarios bien conçus pour générer des fuites (13) ;
 - une phase opérationnelle (17) au cours de laquelle le modèle mathématique qui a été établi entre les mesures du premier groupe de capteurs (9a, 9b) et du deuxième groupe de capteurs (9a, 9b) est utilisé pour la détection, pour la localisation et pour la quantification de fuites (13) dans le réseau de distribution de gaz (1) ;

dans lequel la phase opérationnelle (17) comprend les étapes suivantes dans lesquelles :

- on contrôle les soupapes de surpression dans un ordre prédéterminé et en conformité avec des scénarios bien conçus ;
- on soumet le premier groupe de capteurs (9a, 9b) à une extraction par lecture ;
- en se basant sur ces mesures que l'on obtient via une extraction par lecture, on calcule ou on détermine la valeur du deuxième groupe de capteurs (9a, 9b) à l'aide du modèle mathématique ;
- on compare les valeurs du deuxième groupe de capteurs (9a, 9b), qui ont été calculées ou qui ont été déterminées, aux valeurs du deuxième groupe de capteurs (9a, 9b), qui ont été lues, et on détermine la différence entre elles ;
- on détermine le fait de savoir si l'on se trouve en présence d'une fuite (13) dans le réseau de distribution de gaz (1) sur la base de la différence que l'on a mentionnée ci-dessus et de l'une quelconque de ses dérivées, y compris une quantité mathématique qui peut être extraite de la différence ;
- on génère une alarme lorsqu'une fuite (13) est détectée et/ou on génère un débit de fuite et/ou on génère le coût correspondant à une fuite, ainsi que n'importe quel emplacement lorsqu'une fuite (13) est détectée.

2. Procédé conformément à la revendication 1, **caractérisé en ce qu'**au moins une partie des capteurs de l'écoulement (9a) sont placés à proximité des soupapes de surpression (10), d'une manière telle que l'on puisse mesurer le débit des soupapes de sur-

pression (10).

3. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** le procédé qui est destiné à la phase d'entraînement (16) comprend une phase de démarrage (15) au cours de laquelle les capteurs (9a, 9b) que l'on a mentionnés ci-dessus sont étalonnés avant de les utiliser.
4. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** l'on interrompt de manière temporaire ou l'on arrête la phase opérationnelle (17) à certains moments ; après quoi, on reprend la phase d'entraînement (16) dans le but de redéfinir le modèle mathématique ou entre les mesures des différents capteurs (9a, 9b), avant de procéder au redémarrage de la phase opérationnelle (17).
5. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** l'on répète de manière séquentielle les étapes de la phase opérationnelle (17) à un intervalle de temps donné.
6. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce qu'**un capteur (9a, 9b) est prévu à proximité de chaque soupape de surpression (10) dans le réseau de distribution de gaz (1) et/ou vice versa.
7. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** le modèle mathématique est un modèle du type à boîte noire.
8. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** le modèle mathématique que l'on a mentionné ci-dessus prend la forme d'une fonction matricielle et/ou d'une fonction vectorielle non linéaire avec des paramètres ou des constantes ; dans lequel les changements du résultat ou des "cibles" du modèle mathématique font l'objet d'un suivi au cours de la phase opérationnelle (17).
9. Procédé conformément à l'une quelconque des revendications précédentes, **caractérisé en ce que** le réseau de distribution de gaz (1) est en outre équipé d'un capteur (9c) ou de plusieurs de ces derniers, qui peut/peuvent enregistrer l'état d'une soupape de surpression (10) ou de plusieurs de ces dernières et/ou **en ce que** le réseau de distribution de gaz (1) est en outre équipé d'un capteur de la pression différentielle (9d) ou de plusieurs de ces derniers.
10. Réseau de distribution de gaz mis sous pression ou

mis sous vide, dans lequel le réseau de distribution de gaz (1) est au moins équipé :

- d'une source (6) de gaz comprimé ou de vide ou de plusieurs de ces dernières ; 5
- d'un consommateur (7) ou d'une zone de consommateurs d'applications de gaz comprimé ou de vide ou de plusieurs de ces derniers/dernières ; 10
- de pipelines ou d'un réseau de pipelines (5) pour le transport du gaz comprimé ou du vide à partir des sources (6) en direction des consommateurs (7) ou des zones de consommateurs ;
- d'un certain nombre de capteurs (9a, 9b) qui fournissent un paramètre physique du gaz ou plusieurs de ces derniers à différents moments et à différents endroits au sein du réseau de distribution de gaz (1); 15

caractérisé en ce que le réseau de distribution de gaz (1) est en outre équipé : 20

- d'un certain nombre de soupapes de surpression (10) qui peuvent être contrôlées ou qui peuvent être réglées ; 25
- d'un capteur (9c) ou de plusieurs de ces derniers qui est/sont capable(s) d'enregistrer l'état ou le statut d'une soupape de surpression (10) ou de plusieurs de ces dernières ;
- d'une unité de commande d'acquisition de données (11) qui est destinée à la récolte de données à partir des capteurs (9a, 9b, 9c) et au contrôle ou au réglage des soupapes de surpression que l'on a mentionnées ci-dessus ; 30
- d'une unité de calcul (12) qui est destinée à la mise en oeuvre du procédé en conformité avec l'une quelconque des revendications précédentes. 35

11. Réseau de distribution de gaz conformément à la revendication 10, **caractérisé en ce qu'**un capteur (9a, 9b, 9c) est prévu à proximité de chaque soupape de surpression (10) dans le réseau de distribution de gaz (1) et/ou vice versa. 40

12. Réseau de distribution de gaz conformément l'une quelconque des revendications précédentes 10 à 11, **caractérisé en ce que** le réseau de distribution de gaz (1) est en outre équipé d'un moniteur (14) qui est destiné à afficher ou à signaler des fuites (13), des débits de fuites, des coûts dus à des fuites et des localisations possibles de fuites (13). 45

13. Réseau de distribution de gaz conformément l'une quelconque des revendications précédentes 10 à 12, **caractérisé en ce que** le réseau de distribution de gaz (1) est en outre équipé d'un capteur (9c) ou de plusieurs de ces derniers qui peut/peuvent enregis- 50

trer l'état ou le statut d'une soupape de surpression (10) ou de plusieurs de ces dernières et/ou **en ce que** le réseau de distribution de gaz (1) est en outre équipé d'un capteur de la pression différentielle (9d) ou de plusieurs de ces derniers. 55

14. Réseau de distribution de gaz conformément l'une quelconque des revendications précédentes 10 à 13, **caractérisé en ce que** l'unité de calcul (12) représente une unité de calcul basée sur le cloud (12), qui peut être raccordée sans fil ou non au réseau de distribution de gaz (1). 60

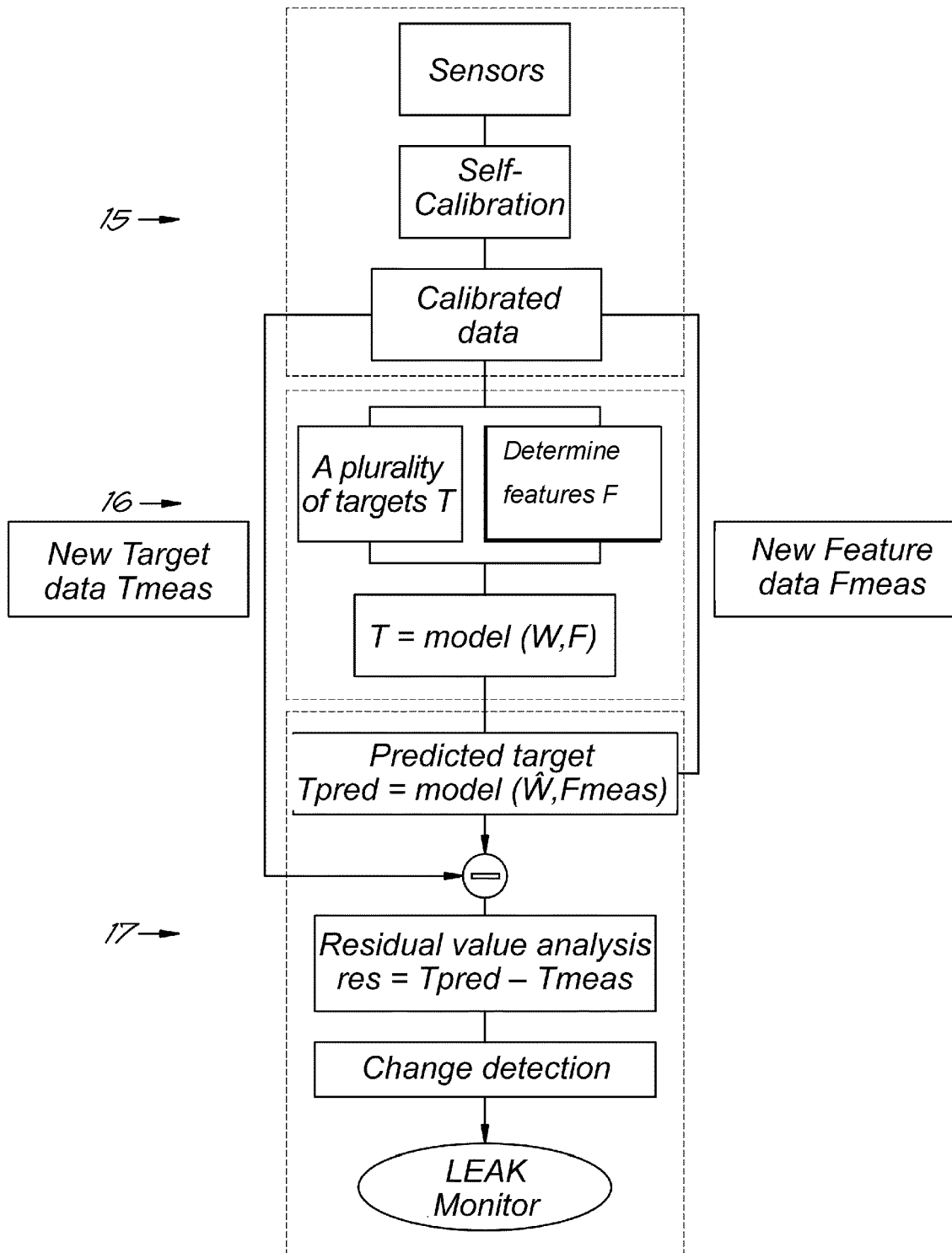


Fig. 2

REFERENCES CITED IN THE DESCRIPTION

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